AP-971

Application Note

Pentium® III Xeon™ Processor with 256KB L2 Cache Thermal Solutions Guidelines

Order number 245246-004
May, 2000

Copies of documents which have an ordering number and are referenced in this document, or other Intel literature, may be obtained from:

Intel Corporation
P.O. Box 7641
Mt. Prospect, IL 60056-7641

or call 1-800-879-4683
or visit Intel’s website at http://www.intel.com

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1. INTRODUCTION

This Application Note is intended to provide information about Intel's reference heat sink solution for the Pentium® III Xeon™ processors with 256KB L2 cache. In addition, alternative processor cooling approaches are discussed.

2. TERMINOLOGY

The following terms are used in this document and are defined here for clarification:

- **Pentium® III Xeon™ processor with 256KB L2 cache -** refers to a Pentium III Xeon processor which utilizes On Cartridge Voltage Regulator technology, or ***"OCVR"***, and which has 256KB of Level 2 cache. The OCVR regulates V_{CC_CORE} (the appropriate cartridge input voltage) to the required processor core voltage (V_{CC_CPU}). The OCVR was developed to provide the necessary regulation to guarantee the highest possible frequency of operation for the Pentium III Xeon processor at 600 MHz and above.
- **Pentium® III Xeon™ processor with 1MB and 2MB L2 cache -** refers to a Pentium III Xeon processor which utilizes On Cartridge Voltage Regulator technology, or ***"OCVR"***, and which has either 1MB or 2MB of Level 2 cache. The OCVR regulates V_{CC_CORE} (the appropriate cartridge input voltage) to the required processor core voltage (V_{CC_CPU}). The OCVR was developed to provide the necessary regulation to guarantee the highest possible frequency of operation for the Pentium III Xeon processor at frequencies of 600 MHz and above.
- **Pentium® III Xeon™ processor at 500 MHz and 550 MHz -** refers to a Pentium III Xeon processor without an OCVR, and requires separate Vcc CORE and L2 voltage sources.
- **Pentium® III Xeon™ processor -** refers to any Pentium III Xeon processor with 256KB L2 cache, Pentium III Xeon processor with 1MB and 2MB L2 cache, or Pentium III Xeon processor at 500 MHz and 550 MHz.
- **L2 cache** —The L2 cache is integrated directly on the processor core for the Pentium III Xeon processor with 256KB L2 cache and the Pentium III Xeon processor with 1MB and 2MB L2 cache, or is located on the substrate for the Pentium III Xeon processor at 500 MHz and 550 MHz.
- **2.8V Pentium® III Xeon™ processor** — refers to a Pentium III Xeon processor with 256KB L2 cache or a Pentium III Xeon processor with 1MB and 2MB L2 cache which can be powered with +2.8 volts applied to its VCC_CORE pins.
- **5/12V Pentium® III Xeon™ processor** — refers to a Pentium III Xeon processor with 256KB L2 cache or a Pentium III Xeon processor with 1MB and 2MB L2 cache which can be powered with either +5.0 or +12.0 volts applied to its VCC_CORE pins.
- **Processor substrate** — The structure on which components are mounted inside the S.E.C. cartridge (with or without components attached).
- **Processor core** — The processor's execution engine.
- **S.E.C. cartridge** — The processor packaging technology used for the Pentium® III Xeon™ processor family. S.E.C. is short for "Single Edge Contact" cartridge.
- **Thermal plate** — The surface used to connect a heat sink or other thermal solution to the processor.

3. REFERENCES

The reader of this Application Note should also be familiar with material and concepts presented in the datasheets, application notes, and other documents for the Pentium® III Xeon™ processor family. These are found at:

http://developer.intel.com/design/pentiumiii/xeon/

4. REFERENCE THERMAL SOLUTION

The reference passive heat sink solution that was designed for the Pentium® III Xeon™ processors at 550 MHz can provide adequate cooling for the Pentium III Xeon processor with 256KB L2 cache up to 733 MHz (based on certain airflow and ambient temperature assumptions, described in greater detail in this document). See Chapter 5 for heat sink ordering information.

4.1 Thermal Assumptions

Table 38 in the latest Pentium® III Xeon™ processor at 500 MHz and 550 MHz datasheet (Order Number 245094) shows the maximum L2 cache power, which does not occur simultaneously with the maximum processor core power. The worst case condition for the thermal design occurs when the processor core is at maximum power and the cache is idle, since the power density is higher in this case. 40.5 Watts is the actual worse case power dissipation for the Pentium III Xeon processor at 550 MHz in this condition.

Since the OCVR component does not come into contact with the processor thermal plate, and its power is removed by conduction through the cartridge substrate (as well as by both natural convection and radiation), the thermal contribution of the OCVR can be derated to 50% of its worst case power dissipation. This analysis is based on previous data from the Pentium II processor in the S.E.C.C. package, where it was concluded that if the thermal grease was removed between the thermal plate and the L2 cache components, 50% of the L2 cache power still dissipates through the thermal plate. Since the OCVR package configuration is similar, 50% of the OCVR power is assumed to be dissipated through the thermal plate.

4.2 Thermal Analysis

The performance of any thermal solution is defined as the thermal resistance between the thermal plate and the ambient air around the processor (θ plate to ambient). The lower the thermal resistance between the thermal plate and the ambient air, the more efficient the thermal solution is. The required θ plate to ambient is dependent upon the maximum allowed thermal plate temperature (T_{PLATE}), the local ambient temperature (T_{LA} – the air around the processor) and the thermal plate power (P_{PLATE}).

$$\boldsymbol{\theta \text{ plate to ambient} = (T_{PLATE} - T_{LA}) / P_{PLATE}}$$

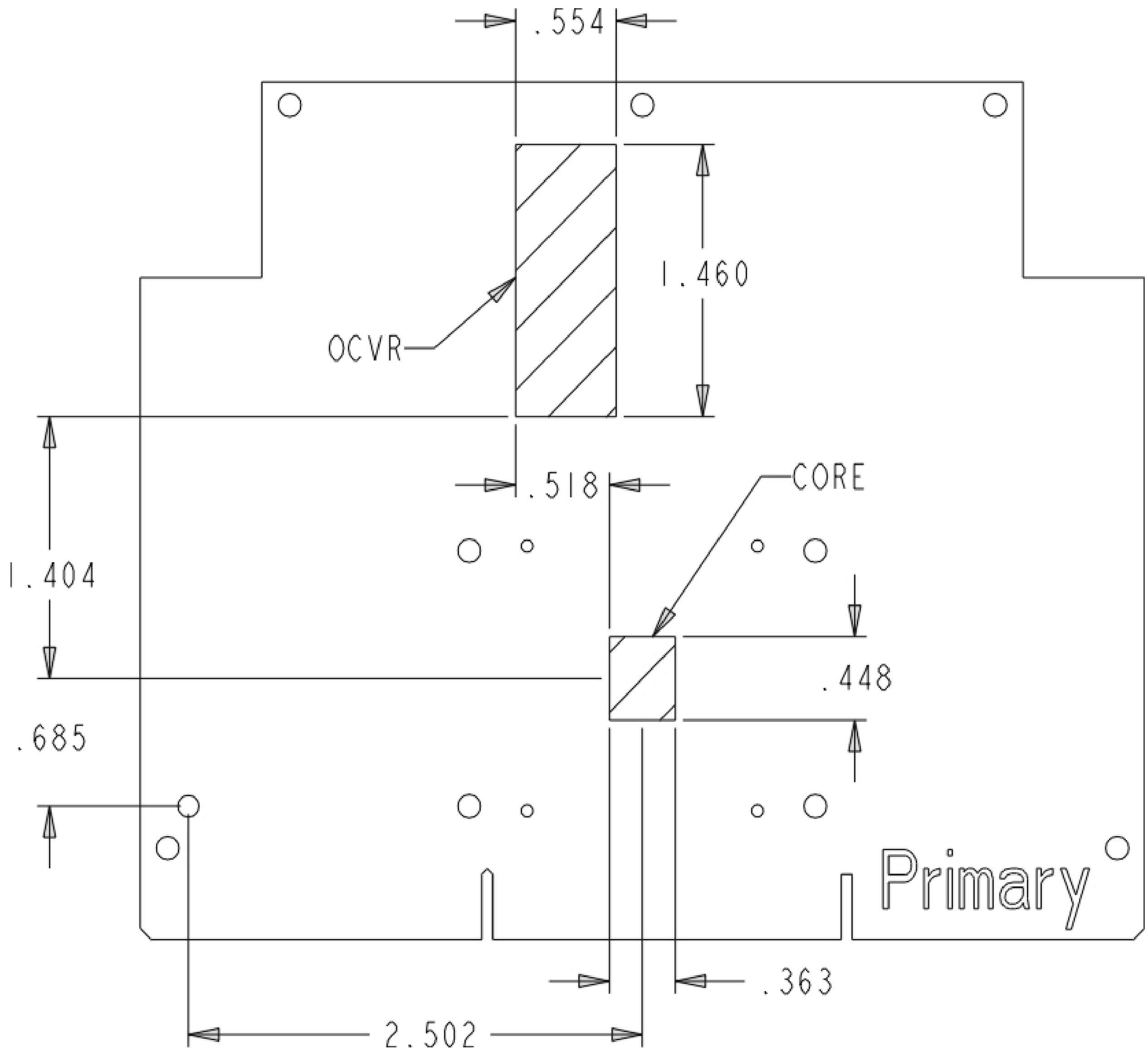

Figure 1. **Thermal density areas of Pentium® III Xeon™ processor with 256KB L2 cache core and OCVR components**

4.3 Thermal Conclusion

The reference passive heat sink will keep the Pentium® III Xeon™ processor with 256KB L2 cache thermal plate temperature at or below its specified value at frequencies up to 733 MHz, if the local ambient temperature (T_{LA}) is maintained at 40°C or less, with an airflow of at least 300 LFM.

5. HEAT SINK SAMPLE INFORMATION

A passive heat sink is available from several vendors, including Thermalloy (part number 22730U-CP35). See Figure 2 below. For more mechanical information refer to Chapter 9 of the latest Pentium® III Xeon™ processor with 256KB L2 cache datasheet (Order Number 245305). For heat sink assembly information contact your Intel representative or contact Thermalloy at:

Thermalloy, Inc.
2021 W. Valley View Lane
Dallas, TX 75234
Tel (972) 488-4257
Fax (972) 488-4461

http://www.thermalloy.com/

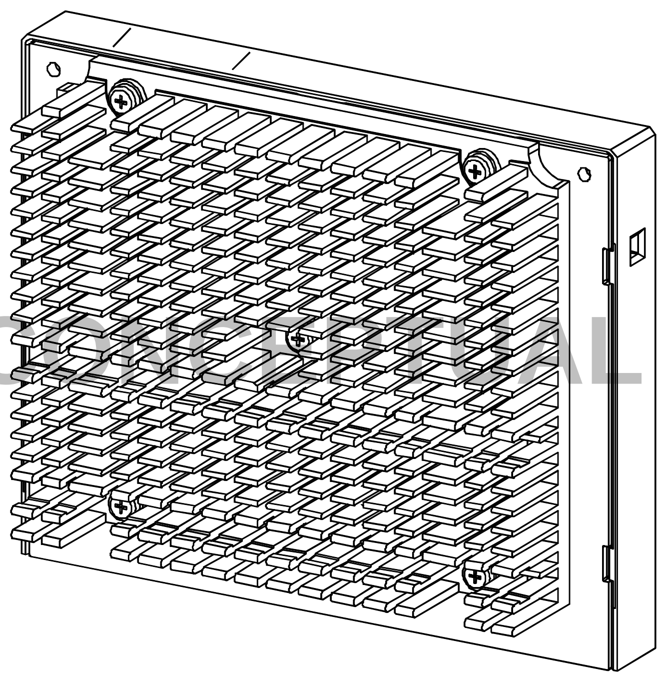

Figure 2. Reference passive heat sink

6. ALTERNATIVE THERMAL COOLING SOLUTIONS

The reference heat sink that was developed for the Pentium® III Xeon™ processors at 550 MHz can be used for Pentium III Xeon processors with 256KB L2 cache up to 733 MHz, if the local ambient temperature (T_{LA}) is maintained at 40°C or less. This may be achieved by providing adequate ducting in the chassis, lowering the external chassis (room) ambient temperature, or changing the chassis airflow efficiency.

If the thermal resistance values cannot be obtained due to reduced processor airflow, increased chassis ambient temperatures, etc., an alternative thermal solution (such as an active heat sink, thermal piping, etc.) may be implemented.

If an active heat sink solution is chosen, then the baseboard designer should consider including fan headers and associated power source budget, as well as fan monitoring circuitry (if required by application). See Section 9.3.2 of the latest Pentium® III Xeon™ processor with 256KB L2 cache datasheet for further information on active heat sink fans.

NOTE: The reference passive heat sink (Thermalloy 22730U-CP35 or equivalent) has been designed to easily accept a 40mm fan if needed. Please refer to Chapter 9 of the latest Pentium® III Xeon™ processor with 256KB L2 cache datasheet.

6.1 Pentium® III Xeon™ Processor with 256KB L2 Cache Bypass Data

The data shown in Figure 3 is presented as a guideline to assist the designer in evaluating the trade-offs associated with designing an alternative cooling solution. The data was obtained using the reference passive heat sink. Bypass is defined as the amount of airflow that is redirected around or away from the processor heat sink, due to various dynamics within a given chassis. As bypass decreases, less velocity is needed to reach the desired thermal resistances (θ_{PA}).

Figure 3 shows how the airflow, bypass area and power relate to thermal resistance. The curves show how airflow and bypass vary for a given power dissipation level.

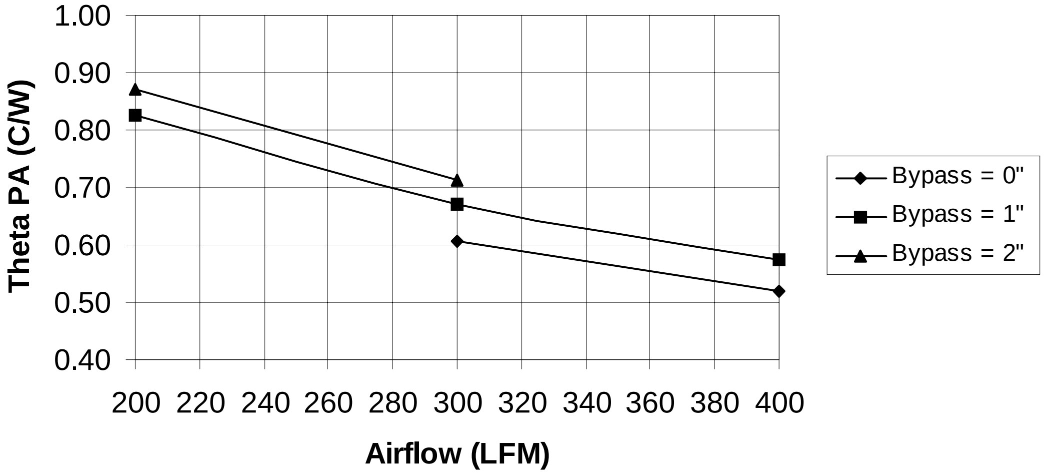

Figure 3. Theta PA vs. Airflow and Bypass

NOTES:

1) Data points taken for various bypass (bypass is the distance of open space around the vertical walls and top of the heat sink).

Using Figure 3, we can also conclude that the reference heat sink can satisfy the thermal requirements for the Pentium III Xeon processor with 256KB L2 cache up to 733 MHz with a 1 inch bypass and 300 LFM, or with a 2 inch bypass and 330 LFM, or at a 2°C lower ambient with 2 inch bypass and 300 LFM. System results may vary depending on particular implementations of chassis thermal margins.

6.2 Pentium® III Xeon™ Processor with 256KB L2 Cache Market Solutions

This section provides the results of tests performed by Intel on thermal solutions available in the marketplace for Pentium® III Xeon™ processors. It is intended to provide the system designer with information on the thermal performance of Pentium III Xeon processor market solutions. The information contained within this section will provide a starting point for the design of processor cooling solutions for Pentium III Xeon processors with 256KB L2 cache.

6.2.1 Test Procedure

All tests were performed using a thermal test vehicle (TTV) which simulates power dissipation from the core using resistive heaters. Power was uniformly distributed over the entire core area. A small groove was machined into the thermal plate of the TTV to allow a thermocouple attachment to the plate without compromising the bond line between the plate and thermal solution. The thermocouple wire position within the groove was fixed with epoxy such that the wire junction was directly above the center of the die.

Thermal grease was used as a thermal interface between the heat sink solution and the TTV; each thermal solution was attached to the TTV with screws. Once mounted, assemblies (TTV + heat sink) were either placed in a wind tunnel or on the lab bench for testing.

Plate and ambient temperatures were recorded. Plate-to-ambient thermal resistance values (theta PA) were calculated based on core power only.

6.2.2 Passive Heat Sink Solution Test Setup

All passive heat sink solutions were tested in a wind tunnel with 2 inches of bypass on the sides and above the heat sink. The assembly was oriented horizontally within the wind tunnel and 300 LFM was supplied across the frontal area of the heat sink and bypass. Air was drawn across the assembly in a direction parallel to the long edge of the cartridge. Figure 4 shows the wind tunnel and variable bypass fixture; the bypass fixture is in the foreground and the wind tunnel is in the background. Power dissipation from the TTV was approximately 24W in all cases. Ambient temperatures were measured with a thermocouple placed at the center of the intake to the wind tunnel and fluctuated between 25°C and 30°C.

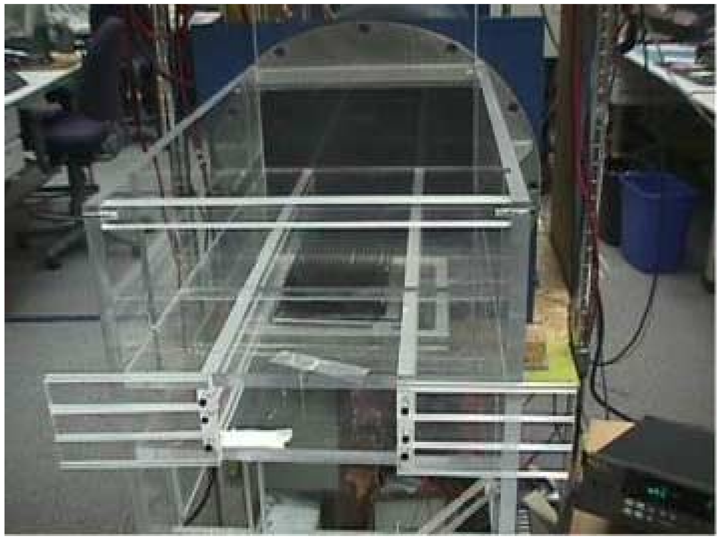

Figure 4. Wind Tunnel Setup for Passive Heat Sinks

6.2.3 Passive Heat Sink Test Results

Three passive heat sink solutions were analyzed, and the respective theta PA values are shown in Figure 5. Thermal resistances for the passive heat sinks range from 0.67 °C/W to 0.71 °C/W. The Thermalloy passive heat sink shown in Figure 6 and the PSC Computer Products passive heat sink shown in Figure 7 are extruded aluminum heat sinks with cross cuts giving each the appearance of a pin-fin heat sink. The surface of the Thermalloy heat sink has been annodized. The folded fin heat sink tested is not available as an industry solution but was included to provide an estimate of the performance of folded fin heat sinks in general. The specific folded fin design tested consisted of an aluminum base with aluminum fins that are attached to the base with epoxy (see Figure 8).

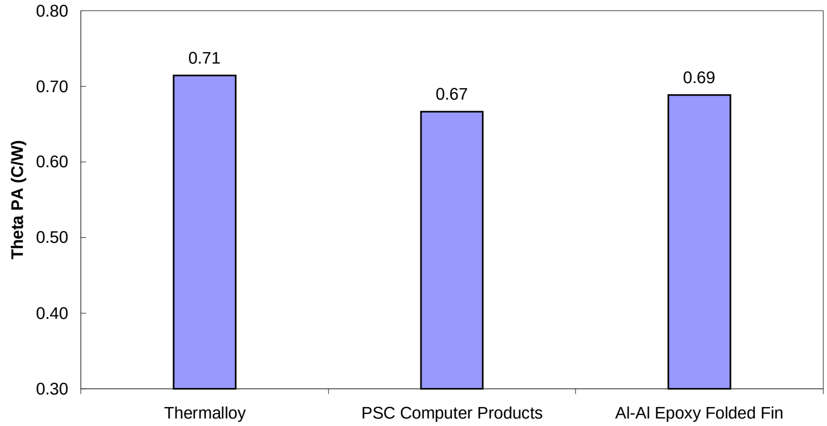

Figure 5. Results of Passive Heat Sink Testing

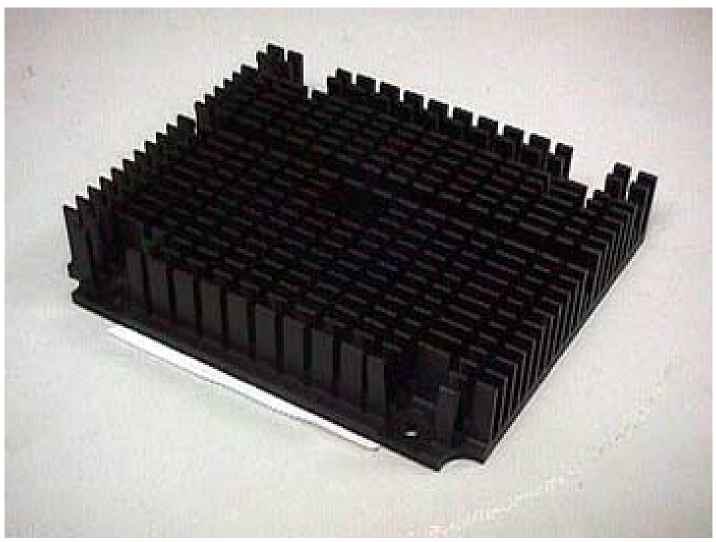

Figure 6. Thermalloy Passive Heat Sink

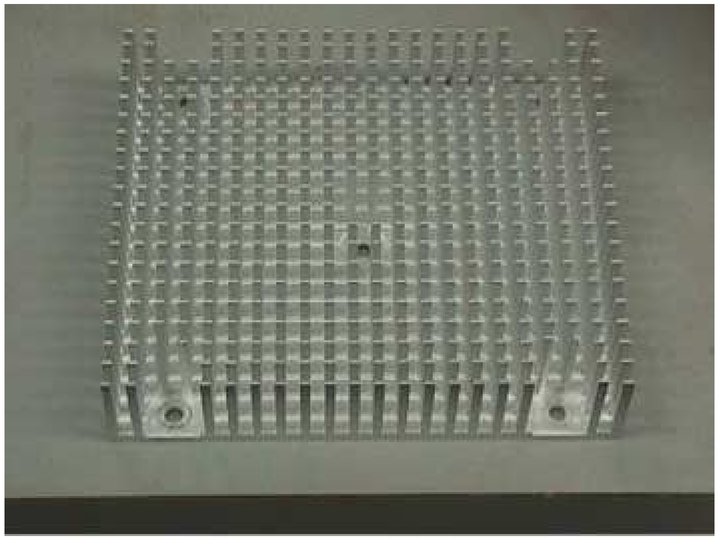

Figure 7. PSC Computer Products Passive Heat Sink

Figure 8. Al-Al Epoxy Folded Fin Passive Heat Sink

6.2.4 Active Heat Sink Solution Test Setup

All active heat sink solutions were tested on a lab bench in a horizontal configuration with an obstruction placed approximately 0.3 inches above the fan. The obstruction consisted of a plate measuring at least 3 fan diameters larger than the fans on the thermal solution, in all directions. Testing in this configuration assumes that a system will have some obstruction preventing the flow of fresh air to an active heat sink, such as is possible in a multi-processor system. Power dissipation from the TTV was approximately 24W in all cases. Ambient temperatures were measured with a thermocouple mounted perpendicularly through the obstruction and centered directly above the fan hub. Figure 9 shows the test setup for active heat sinks. The obstruction is a cardboard plate; in the photo, the obstruction has been placed vertically behind the setup for viewing purposes.

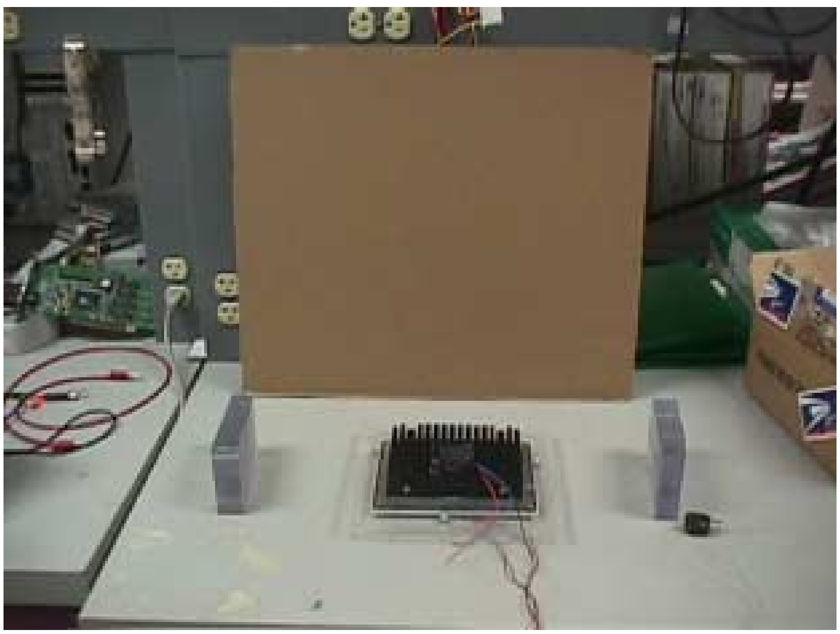

Figure 9. Test Setup for Active Heat Sinks

6.2.5 Active Heat Sink Test Results

Both single and dual fan solutions were tested. Dual fan solutions provided more airflow to the processor; however, depending on the solution, the use of two fans may raise reliability issues. Single fan solutions generally have a lower MTBF rating, but may not provide the amount of cooling required.

Active solutions tested include the Global WIN and PC Power & Cooling dual fan solutions and the Thermalloy passive heat sink modified to include a fan. Test results are shown in Figure 10. Thermal resistances for the active heat sinks range from 0.43 °C/W to 0.63 °C/W.

The Global WIN FAX08 is a dual fan plate fin extruded heat sink (Figure 11). The fans are oriented such that one is directly over the CPU on the lower half of the cartridge and the other covers the upper half of the cartridge. Both fans are 50mm and are centered horizontally on the heat sink. The thermal resistance for this heat sink was calculated using the local ambient above the lower fan.

PC Power & Cooling manufactures the Dual CPU-Cool® X2 fan heat sink (see Figure 12). The heat sink is die cast aluminum with two 50mm fans. The fans are horizontally oriented with one fan near the edge (suggested leading edge for airflow) and the other such that the fan blades pass over the center of the CPU. Thermal resistances were calculated for each fan; since neither fan was situated directly over the processor, a linear interpolation between the two values was taken as the thermal resistance over the CPU for the heat sink. This value is shown in Figure 10.

A fan was added to the Thermalloy passive heat sink to enhance airflow over the CPU (see Figure 13). In order for the heat sink and fan to fit within a 1" height restriction, fins in the area of the CPU were shortened to accommodate a 40mm fan.

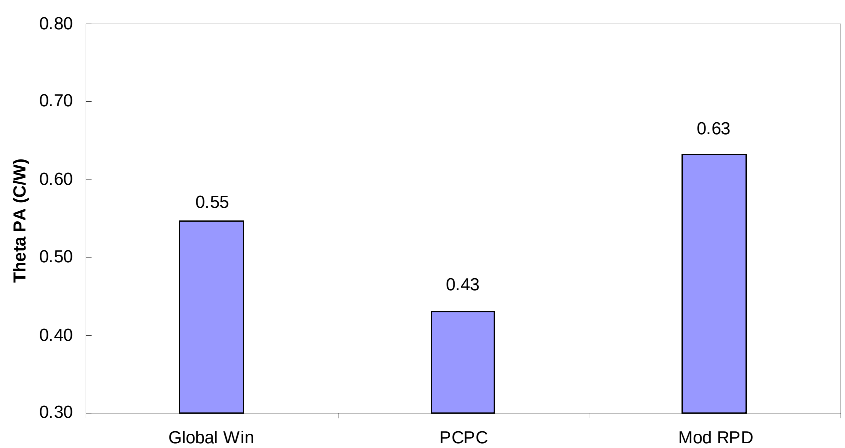

Figure 10. Results of Active Heat Sink Testing

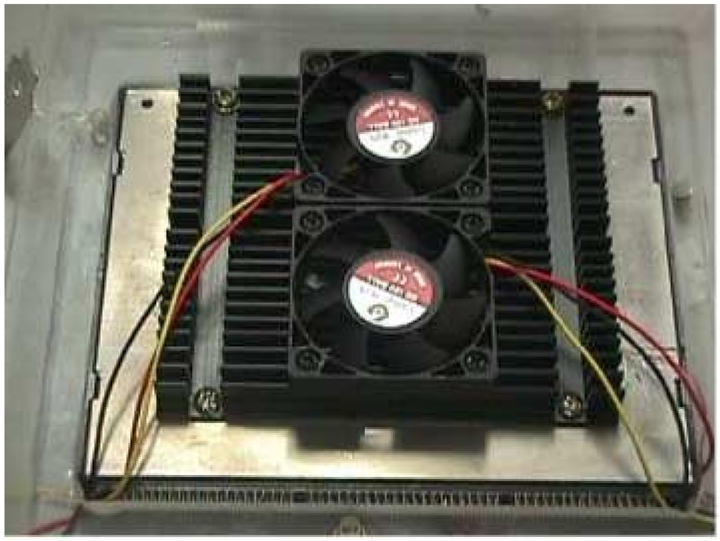

Figure 11. Global Win Dual Fan Heat Sink

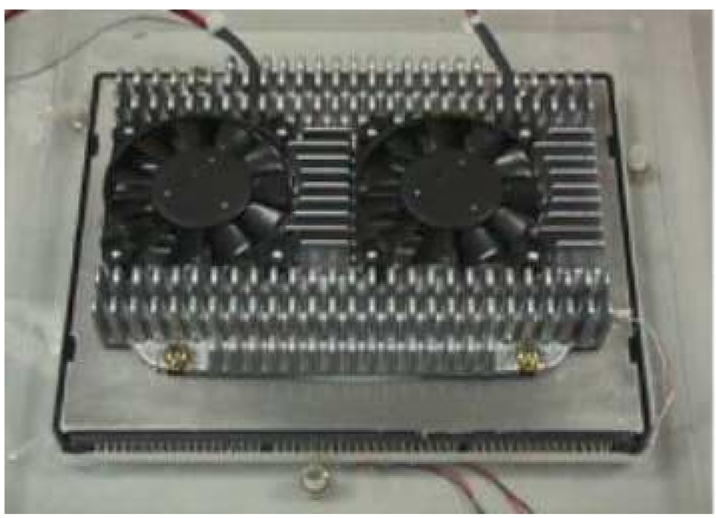

Figure 12. PC Power & Cooling Dual Fan Heat Sink

Figure 13. Modified Thermalloy Heat Sink with 40mm Fan Attached

6.2.6 Ordering Information

PC Power & Cooling, Inc.
5995 Avenida Encinas
Carlsbad, CA 92008
(Tel) 800-722-6555
(Fax) 760-931-6988
http://www.pcpowercooling.com

PSC Computer Products
451 Constitution Ave #E
Camarillo, CA 93012-8515
(805) 388-8030
http://psc-cp.com/

Acadia Technology Inc. (Global WIN US Office)
540 Weddell Drive, Suite 5
Sunnyvale, CA 94089, USA
(Tel) 408-747-1349
(Fax) 408-747-1352
http://www.cooltium.com/English/Home.htm

7. COMMON QUESTIONS

Q: If my present chassis and heat sink was designed to accommodate the Pentium® III Xeon™ processor at 550 MHz, will I have to perform additional thermal analysis?

A: Yes. Even though data indicates the present Pentium III Xeon processor at 550 MHz heat sink will support all Pentium III Xeon processors with 256KB L2 cache at frequencies up to 733 MHz, if the local temperature can be held to 40°C, Intel still recommends performing a thermal analysis of your system.

Q: Does Intel plan on enabling any other heat sink solution (other than the Thermalloy 22730U-CP35 or equivalents)?

A: There are additional heat sink vendors at the Intel developer website that may have solutions that could meet your needs. Refer to:

http://developer.intel.com/design/pentiumii/xeon/components/